

A Preliminary Comparison of MDA and LLSD Performance and Properties

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CIMMS/NSSL

Inference Engines

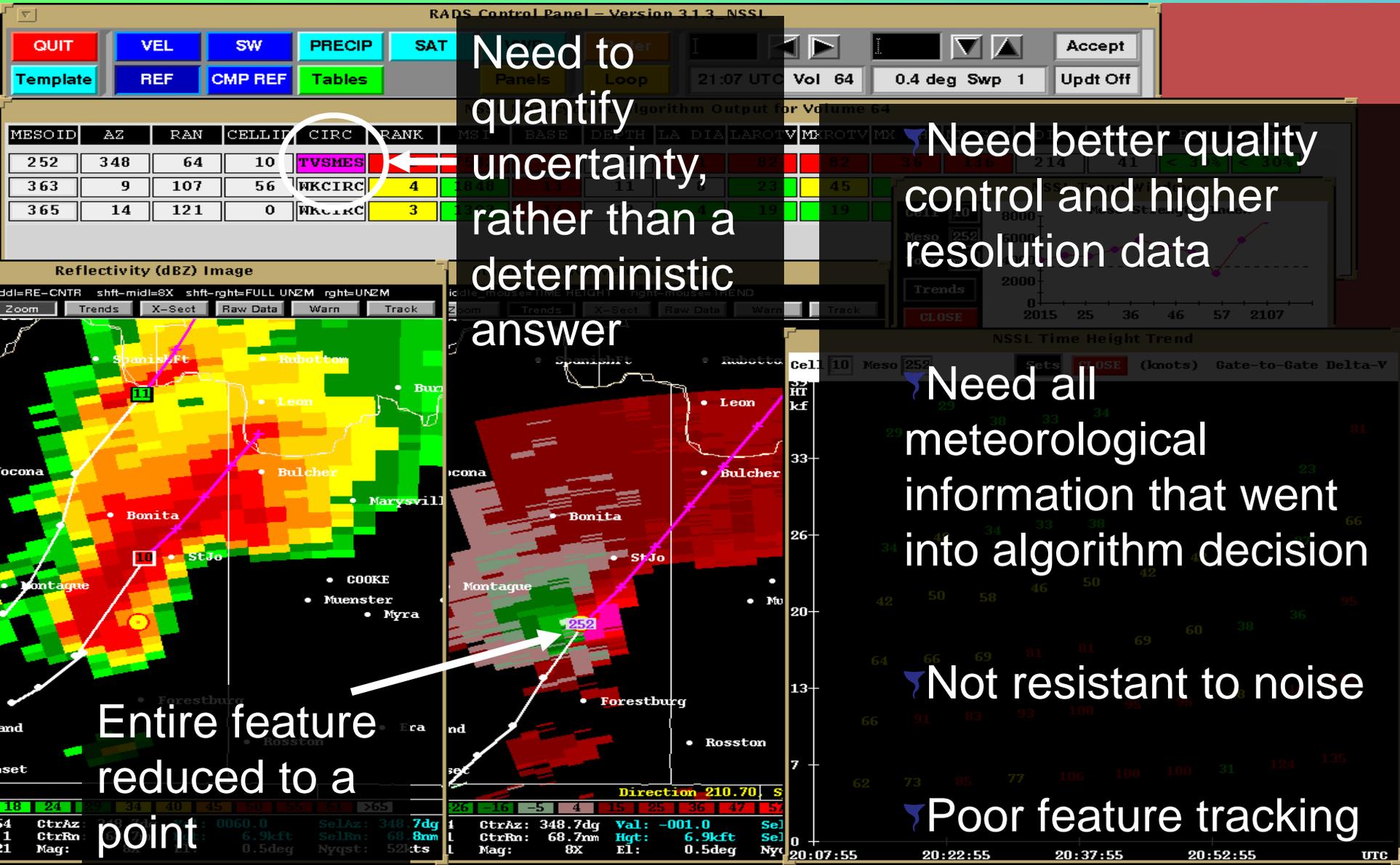
- To identify mesocyclones in single Doppler radar an “inference engine” must identify areas of azimuthal shear, fundamentally a derivative of radial velocity w.r.t. azimuthal distance:

$$\frac{\partial u}{\partial \theta_d}$$

where u is radial velocity and θ_d is the distance in azimuth between samples (approximately $\Delta\theta \times r$).

- MDA relies on a peak-to-peak derivative estimate.
 - NOT resistant to noise.
- A local linear least squares derivative (LLSD) estimate is more resistant to noise, especially if u is first filtered to remove extreme values

Current MDA



Local Linear Least Squares Derivative (LLSD)

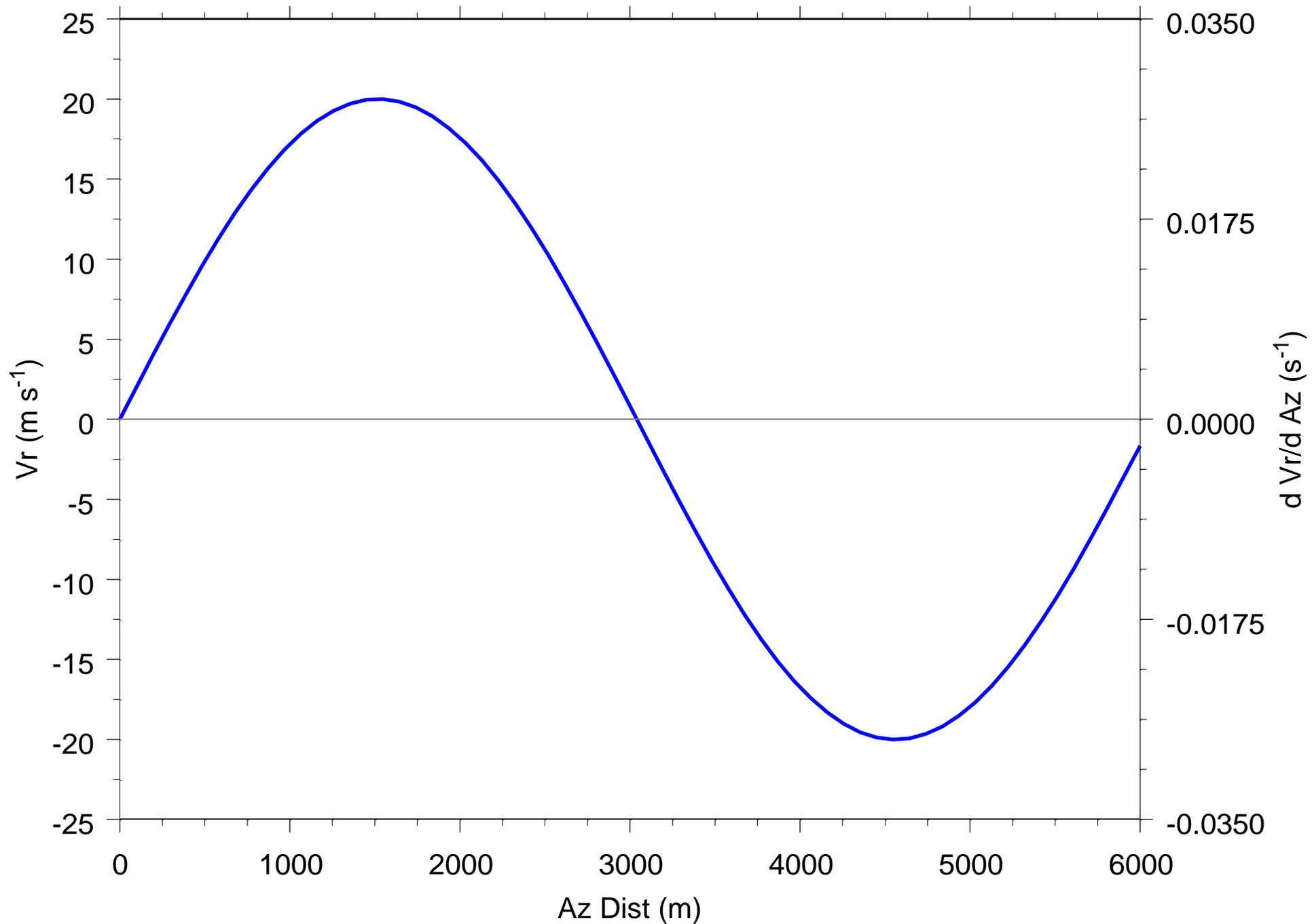
- Draws upon long standing techniques that use local regression fits, rather than global fits, as filtering operations.
- Fits are first order, thus the regression coefficient is used as the derivative estimate:

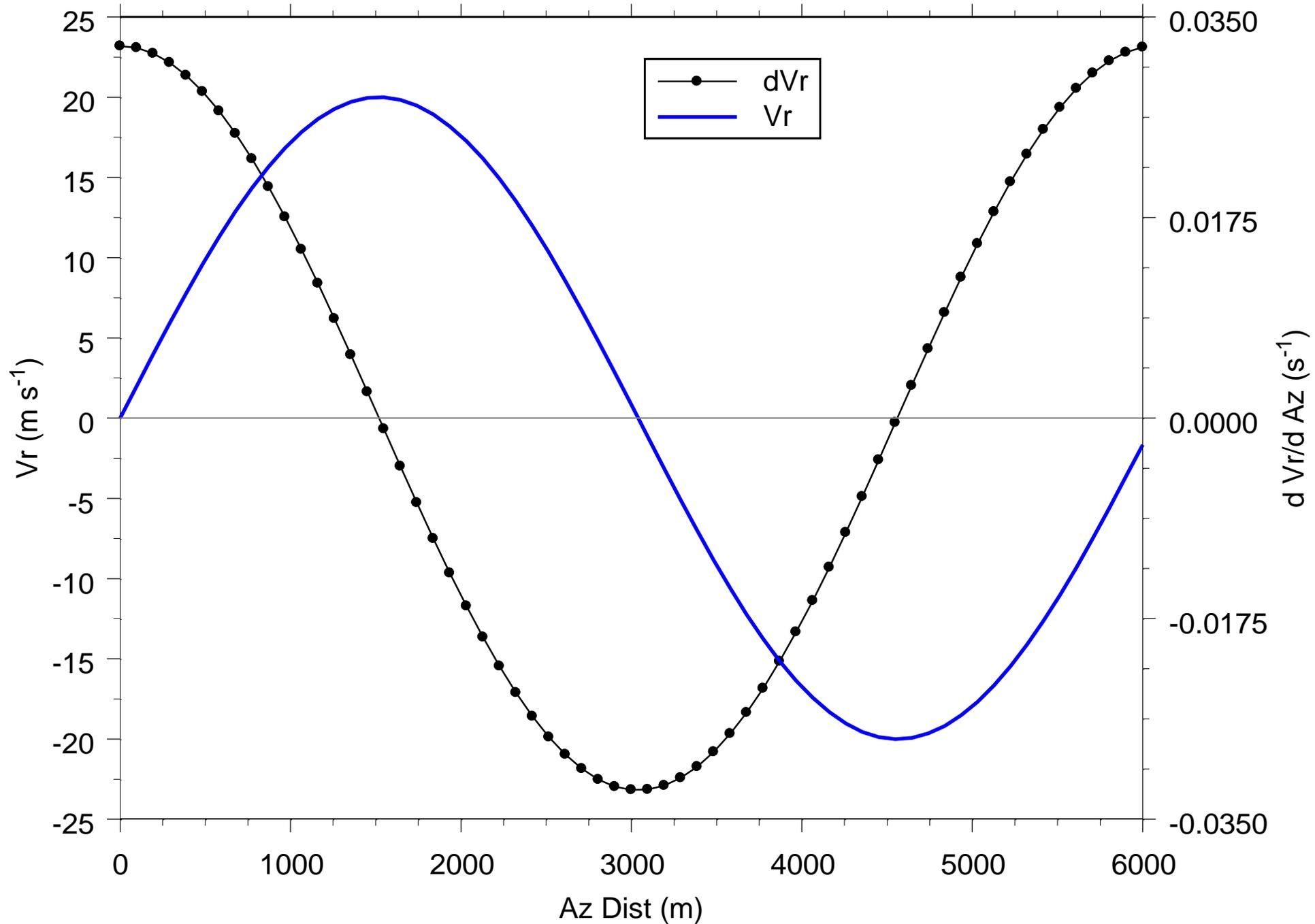
$$y = mx + b,$$

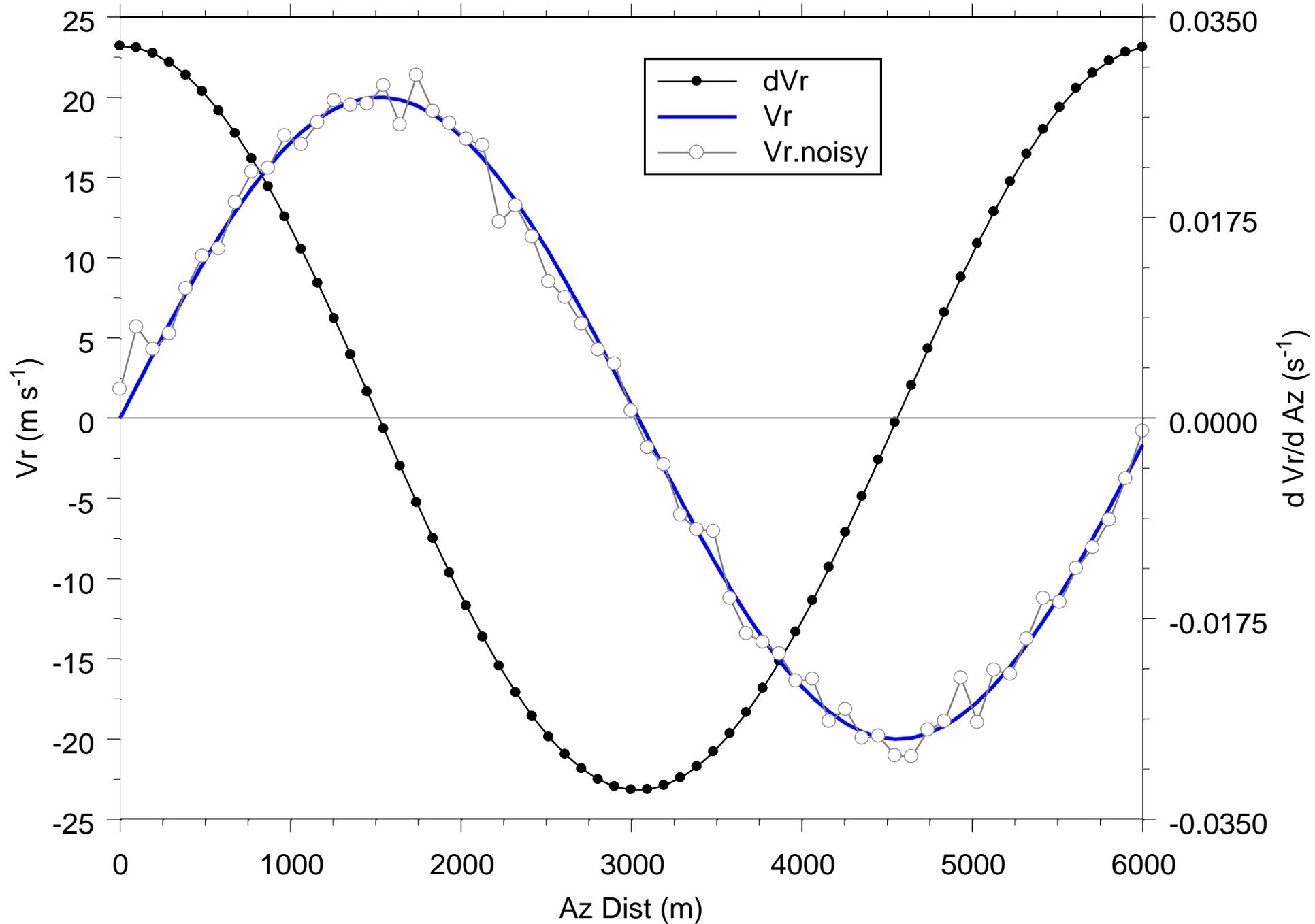
where y is, say, radial velocity and x is location. The regression coefficient is approximately the local derivative, y_x .

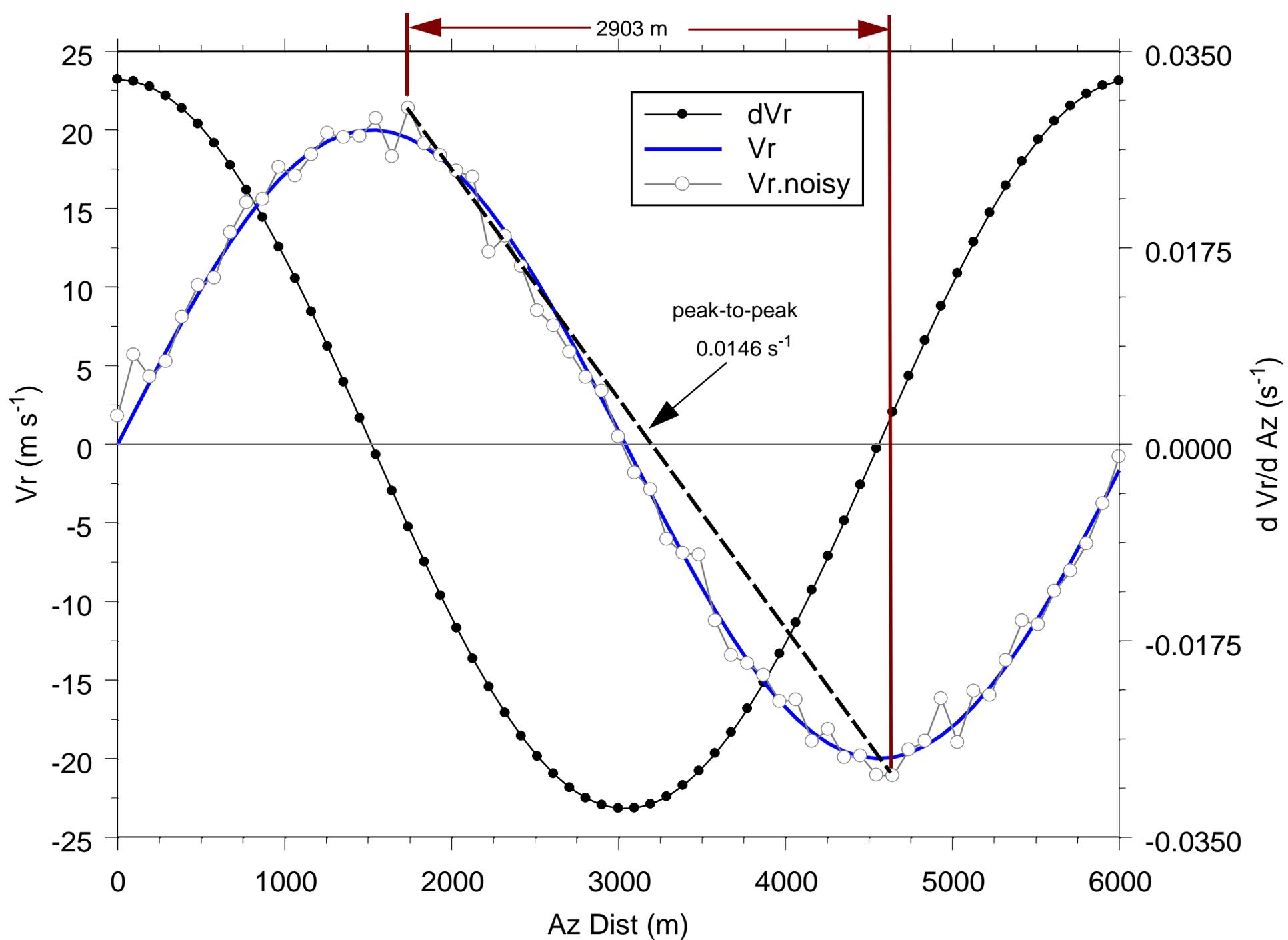
A Toy Example in 1D

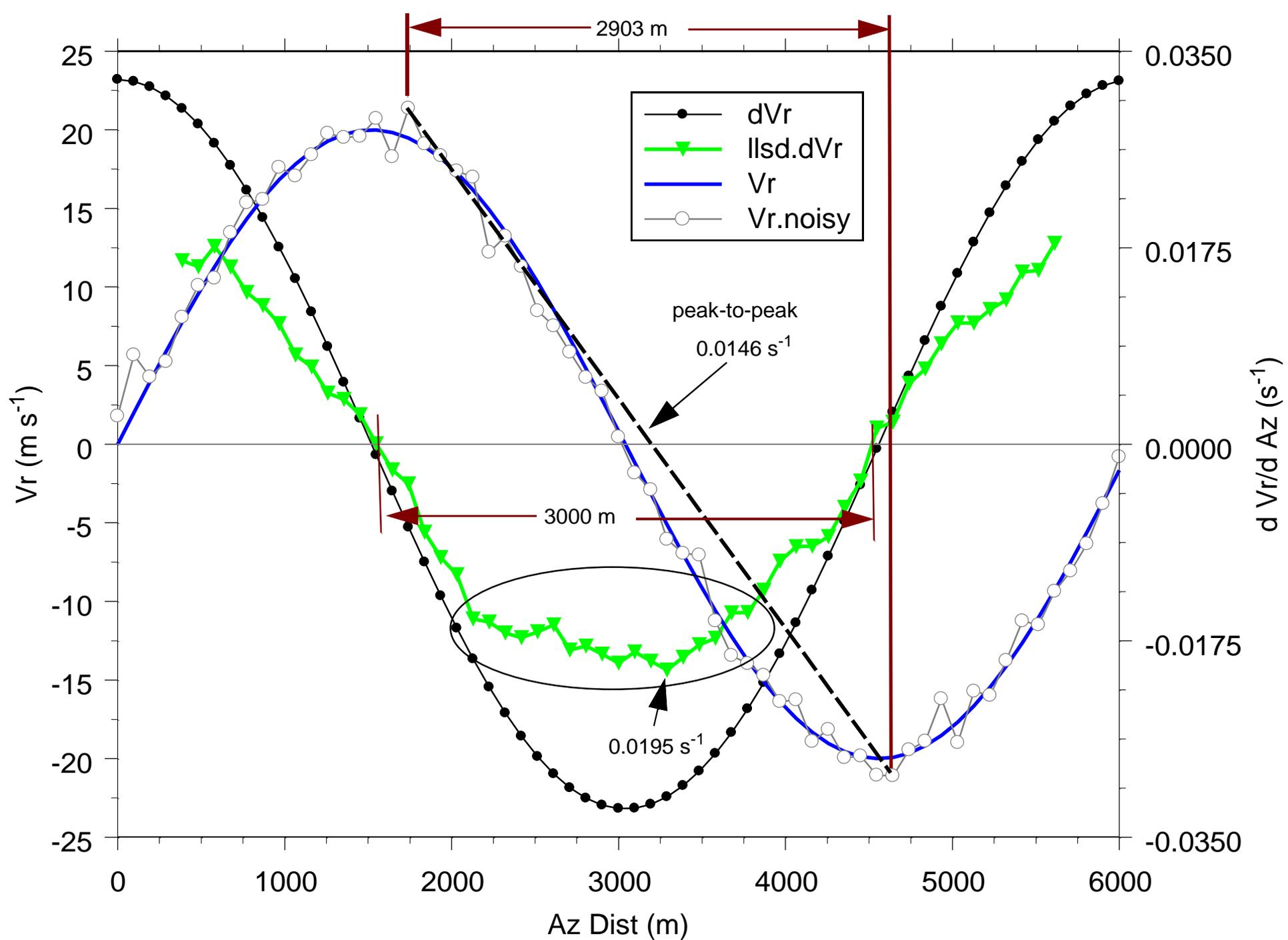
- Procedure:
 - Start with an analytic function (sine)
 - Add noise (Gaussian)
 - Estimate derivative using peak-to-peak and LLSD
 - Show difference between analytic derivative, peak-to-peak, and LLSD











What about 2D?

- Expansion to 2D results in fitting a plane to a $n \times n$ “window” or kernel of u rather than simply n points along each a ring of constant range.
- Advantages: a single application yields both azimuthal and radial derivatives.
 - Azimuthal is analogous to vorticity
 - Radial is analogous to divergence
 - Both derivatives are locally orthogonal.
- LLSD acts as a filter on the entire radial velocity field. Width of the kernel filter is dependent on range from the radar.
- The LLSD used in the report is 2D, using a 5×5 window (five gates in range and five beams in azimuth).

2D LLSD: Nuts and Bolts

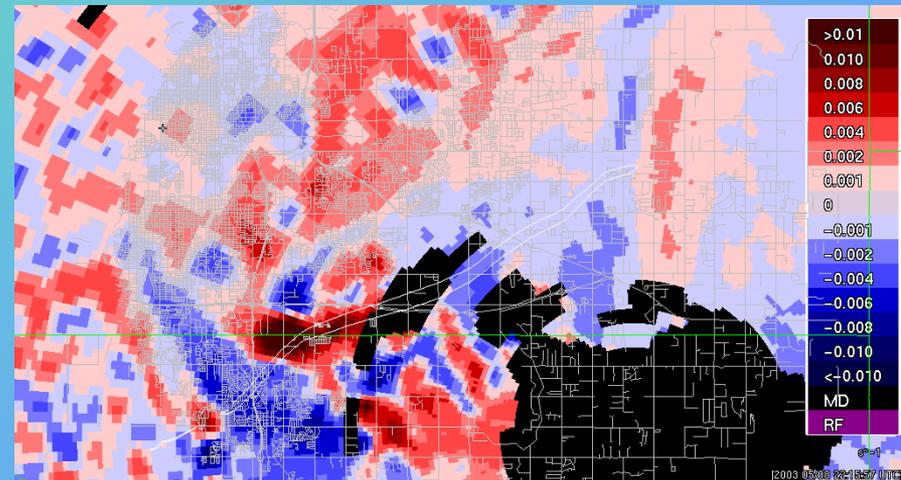
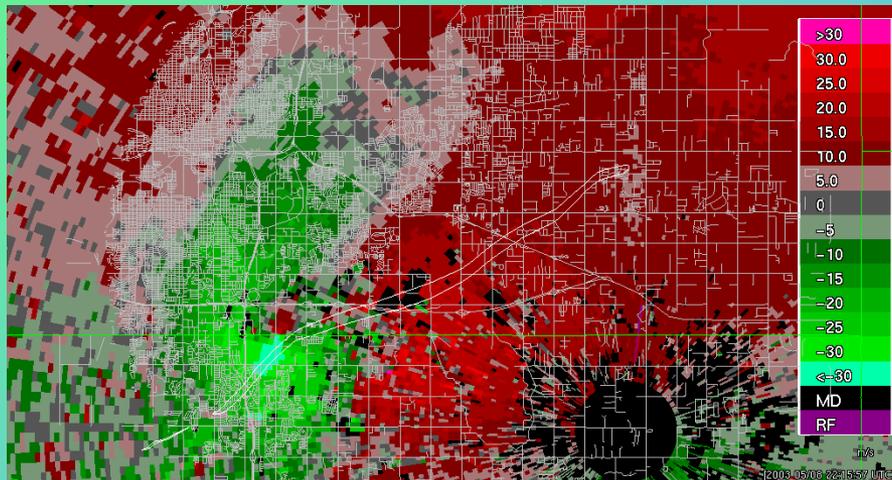
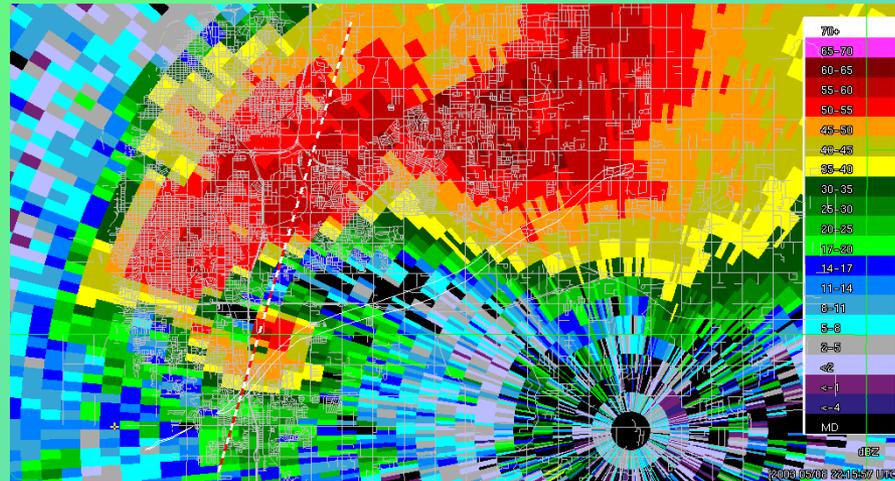
- The LLSD is a filter applied to the entire radial velocity field. Width of the kernel filter is dependent on range from the radar. With some algebra, the orthogonal derivatives u_r and u_s are:

$$u_r = \frac{\sum i u_{ij} w_{ij}}{\Delta r \sum i^2 w_{ij}} \quad u_s = \frac{\sum s_{ij} u_{ij} w_{ij}}{\sum (\Delta s_{ij})^2 w_{ij}}$$

- where u_{ij} is the radial velocity at (i,j), Δr is the pulse volume depth in range, s_{ij} is the azimuthal distance from the center of the window to the point (i,j), and w_{ij} is a uniform weight function.
- Because u_r and u_s are derived from only the radial component of the wind, they are approximations of one half the horizontal divergence and vertical vorticity, respectively, assuming a locally symmetric wind field.

u_s from Real Data

3 May 1999

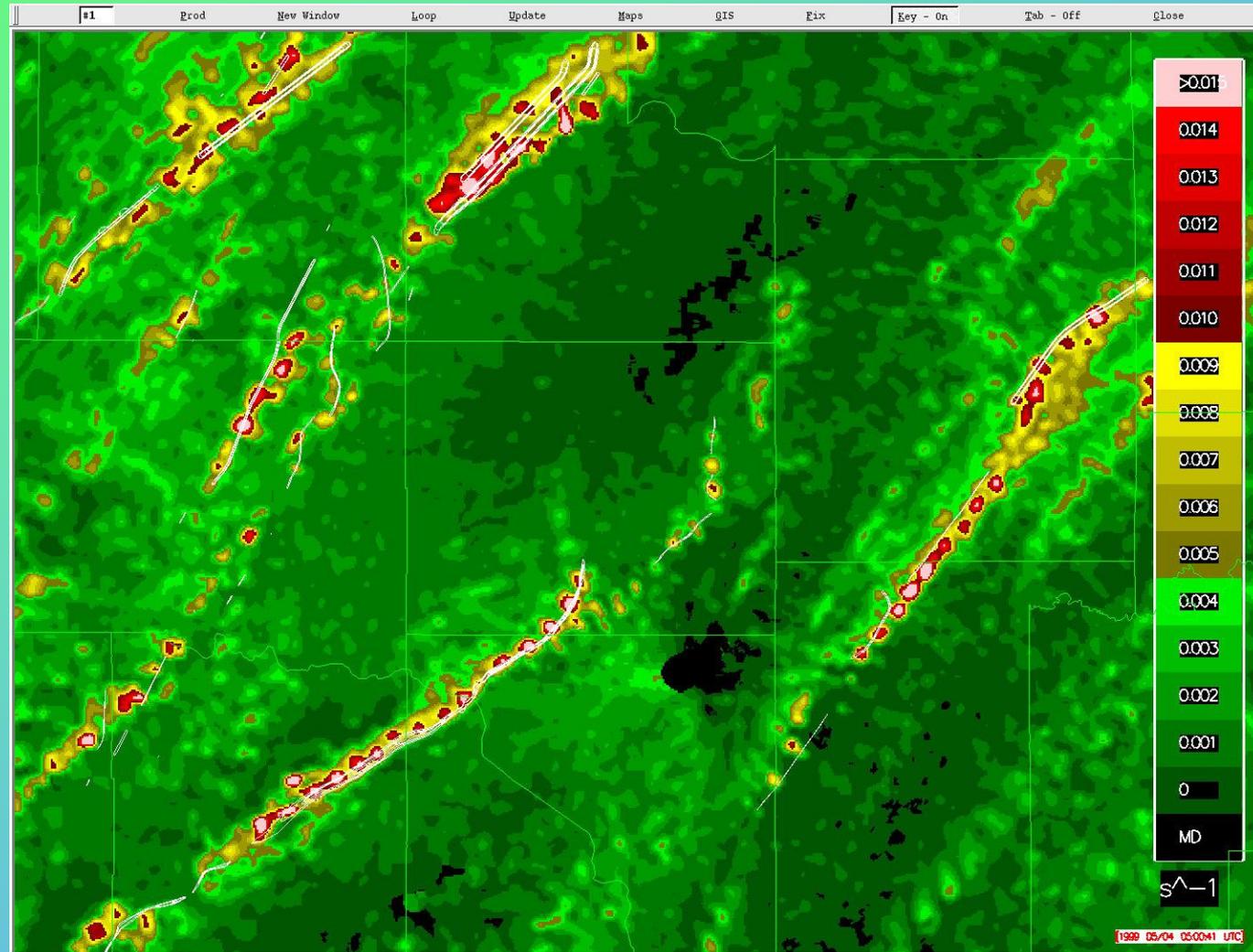


Algorithm Outline for Mesocyclone Tracks from 2D LLSD

- Calculate u_s
- Remove sharp “spikes” caused by dealiasing errors and bad velocity data
- Threshold based on reflectivity
 - Include only data in and near storms; non-precipitation echoes removed as well
- Generate layer maxima
 - Max in 0-3 km AGL
 - Max in 3-6 km AGL

Mesocyclone Tracks 3 May 1999

The 6-hour maxima of u_s shows the tracks of strong circulations. The overlaid white lines show the tracks of tornado damage for this case, as determined from ground and aerial surveys.

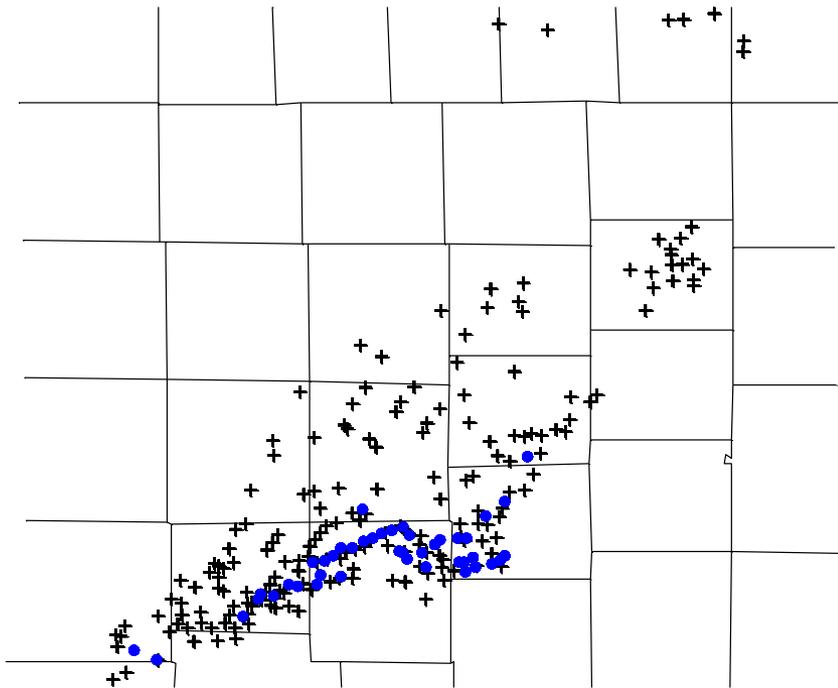


The Report

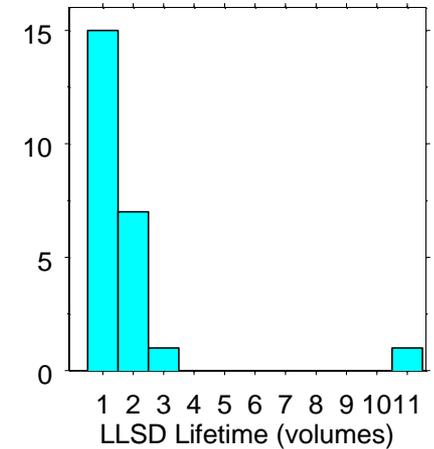
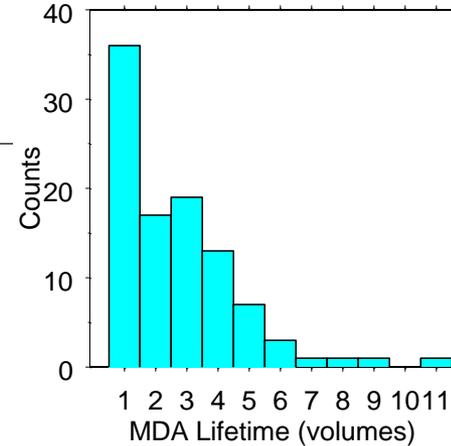
- Compare Build 12 ORPG MDA to a rudimentary LLSD inference engine run on WDSSII system.
- VCP 12 used throughout
- Seven cases, all from Witt (2008): KICT, KDDC, KDMX, KFTG, KGLD, KMPX
- Output: lat, lon, strength rank (MDA only) and circulation ID number (used to assess coherency)
- LLSD values subject to K-means clustering to identify contiguous areas of cyclonic shear of cyclonic shear greater than 0.006 s^{-1} for areas of 25, 60 and 90 km^2 (in report scales 0, 1, and 2). Two levels: 0-3 km AGL and 3-7 km AGL. Note: no optimization for circulation coherency for LLSD.

KICT: a “moderate” case

KICT Low-Level Scale 0



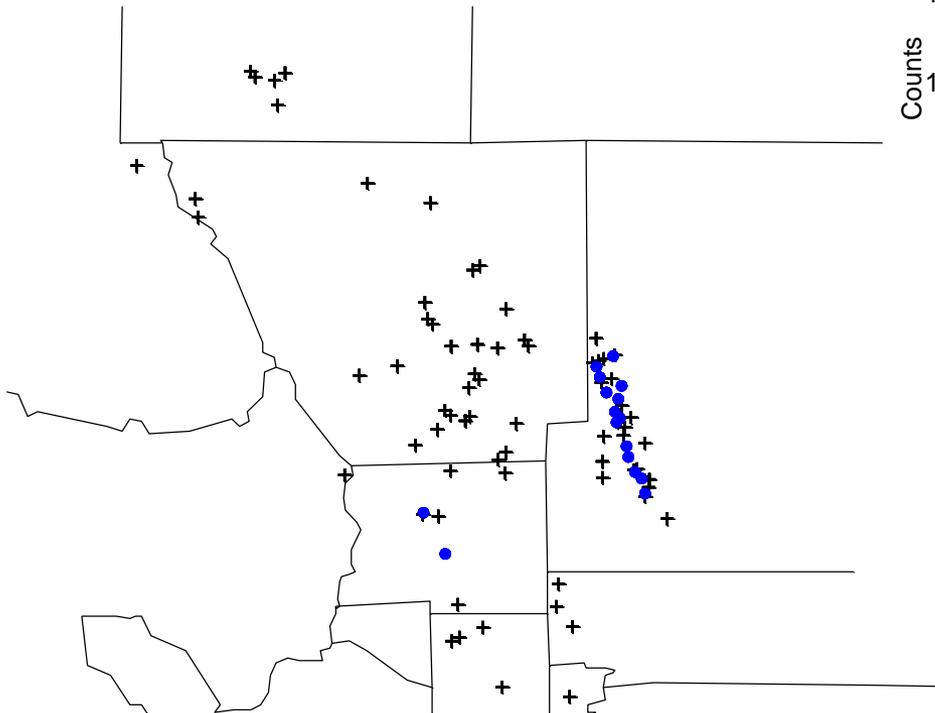
Circles = LLSD, + = MDA



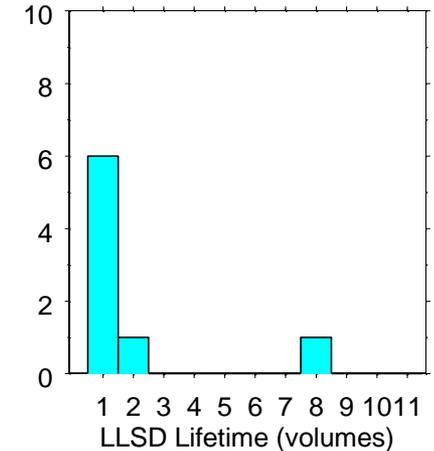
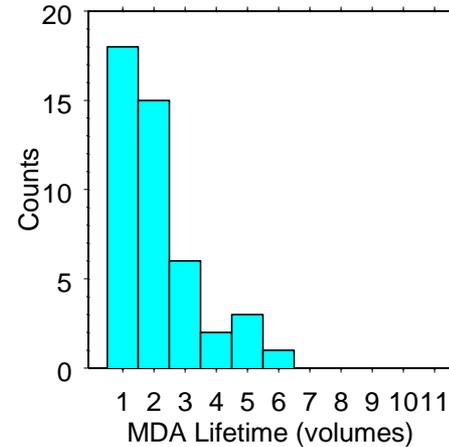
- Many more detections from MDA than LLSD
- MDA: 201 detections with 99 uniques.
- LLSD: 43 detections with 24 uniques
- Mean lifetime for MDA = 2.7 volumes, LLSD = 1.8 volumes
- Mean lifetime difference significant at $p = 0.03$

KFTG: a “light” case

KFTG Low-Level Scale 0



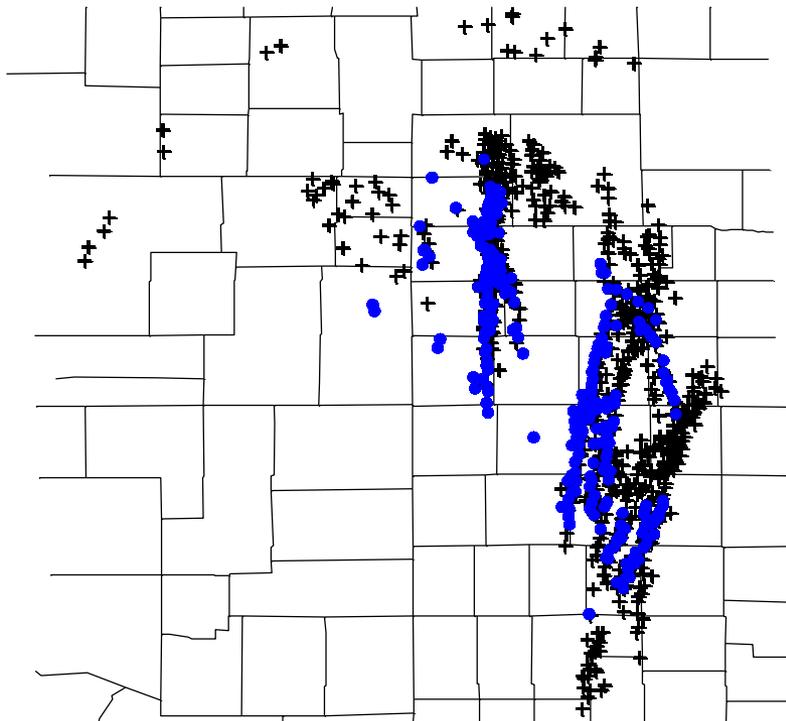
Circles = LLSD, + = MDA



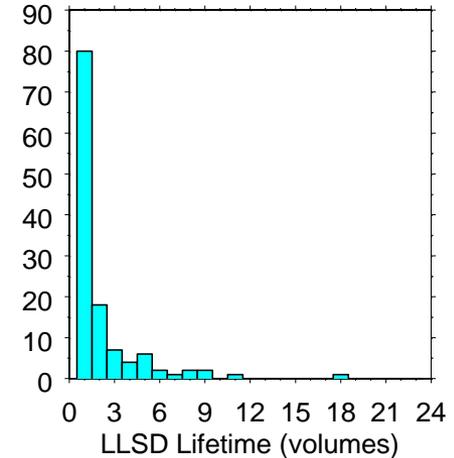
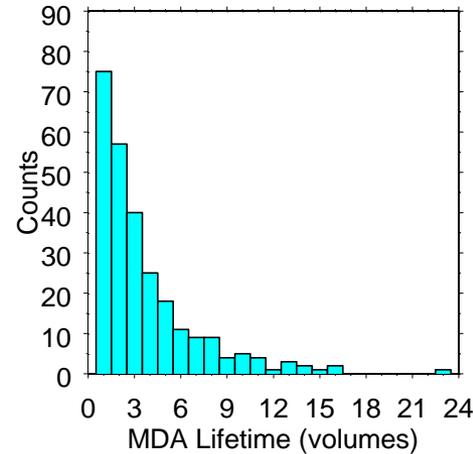
- Many more detections from MDA than LLSD
- MDA: 95 detections with 45 uniques.
- LLSD: 16 detections with 8 uniques
- Mean lifetime for MDA = 2.1 volumes, LLSD = 2.1 volumes
- Mean lifetime difference insignificant.

KGLD: an “active” case

KGLD-A Low-Level Scale 0



Circles = LLSD, + = MDA



- Again, any more detections from MDA than LLSD
- MDA: 979 detections with 267 uniques
- LLSD: 265 detections with 124 uniques Mean lifetime for MDA = 3.7 volumes, LLSD = 2.1 volumes
- Mean lifetime difference significant at $p < 0.005$

Aggregate Characteristics

Algorithm	Detections	Uniques	Mean Lifetime	Max Lifetime
MDA	2159	687	3.14	23
LLSD 0 Low	573	285	2.01	18
LLSD 1 Low	351	186	1.89	18
LLSD 0 Mid	873	420	2.01	30
LLSD 1 Mid	515	222	2.13	18

Concluding Points

- LLSD produces more visually coherent detections than does MDA (even though MDA coherent lifetimes are longer)
- Difference due to years of work to make MDA coherent in space/time while almost no such work has been expended on LLSD (results shown here use an experimental K-means technique optimized for reflectivity cell tracking)
- Thus, LLSD performance is even more promising
- MDA that uses an LLSD inference engine will reduce workload and fatigue for operational meteorologists

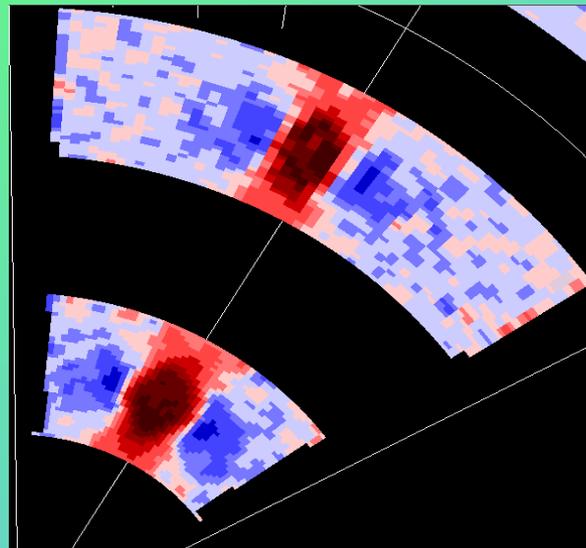
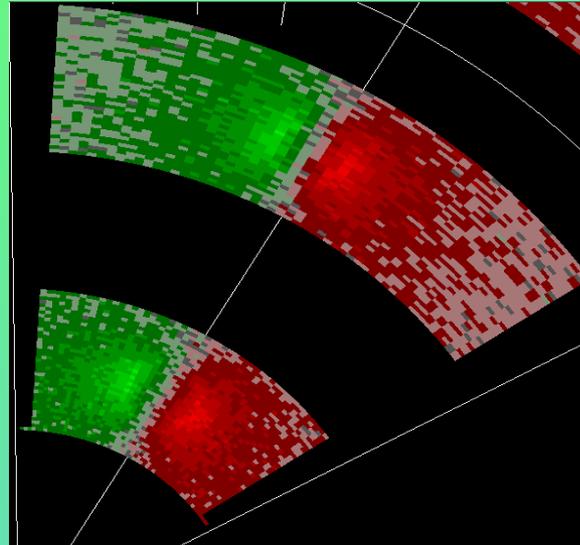
More Concluding Points

- Implementation will require:
 - Develop subject matter expert “truth” data sets for testing and development using super-res data
 - Develop optimal spatial scale and vertical association scales; spatial scales and thresholds for u_s may need to vary with height and/or range.
 - Optimize space/time tracking based on “truth” data sets.
 - LLSD offers a way to easily blend data from different radars.

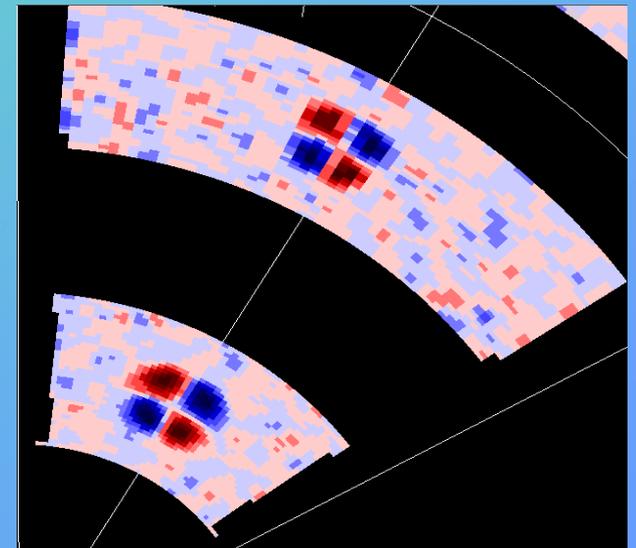
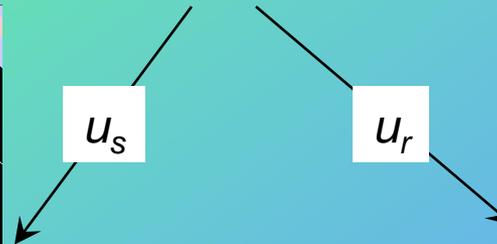
Questions?

Backup/Reserve Slides

Some 2D Synthetic Data Results



Azimuthal shear



Divergence

azimuth

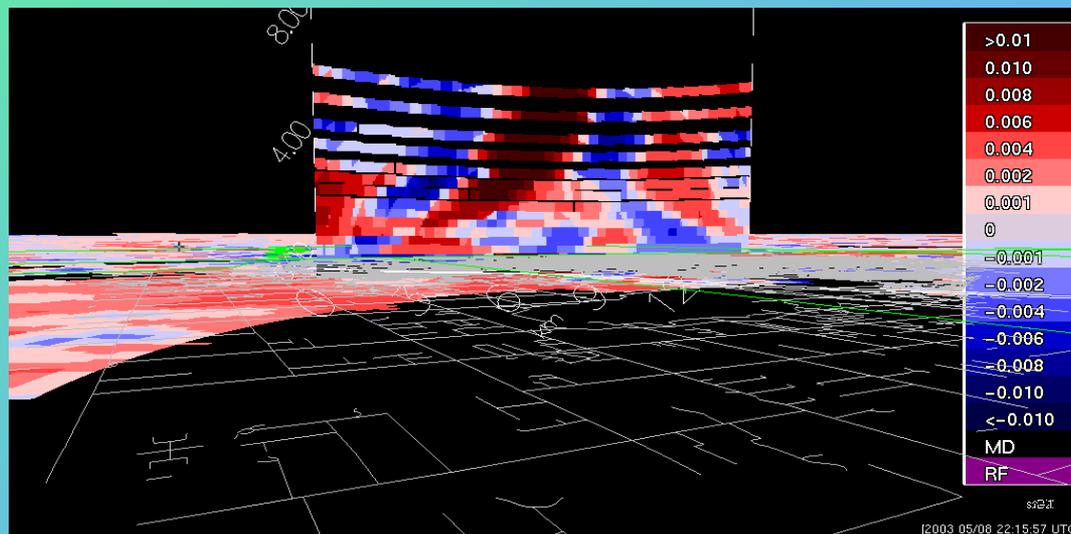
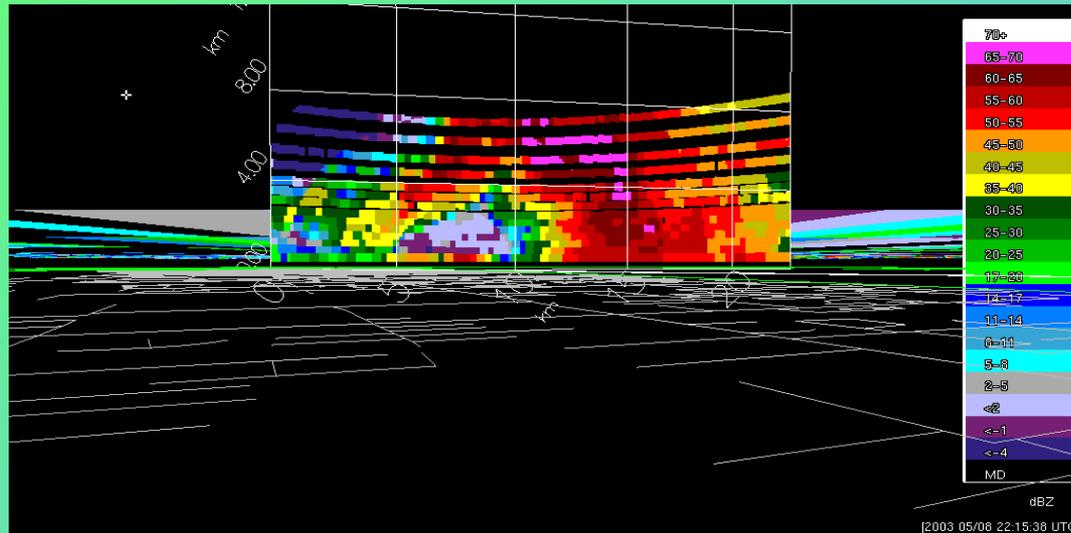
range

	256.27	256.77	257.26	257.74	258.26	258.76	259.26	259.77	260.25	260.76	261.27	261.76	262.25	262.79	263.26	263.78
93.88	-4.86	5.83	5.83	-0.97192	-6.80	-8.75	-6.80	-8.75	-6.80	-10.69	-13.61	-8.75	-7.78	-14.58	-13.61	-13.61
93.62	-2.92	2.92	3.89	-0.97192	-7.78	-9.72	-8.75	-16.52	-17.49	-12.63	-8.75	-7.78	-13.61	-14.58	-14.58	-16.52
93.38	-0.97192	-1.94	1.94	-1.94	-5.83	-8.75	-12.63	-10.47	-11.66	-16.52	-4.86	-9.72	-10.69	-16.52	-11.66	-12.63
93.12	-3.89	-4.86	-2.92	-5.83	-9.72	-11.66	-18.47	-14.58	-6.80	-10.69	-7.78	-11.66	-8.75	-12.63	-16.52	-13.61
92.88	-3.89	-3.89	-2.92	1.94	-7.78	-14.58	-18.47	-20.41	-15.55	-1.94	7.78	-4.86	-3.89	-9.72	-10.69	-10.69
92.62	-6.80	-8.75	-3.89	0.00000	-5.83	-21.38	-22.35	-21.38	-12.63	4.86	5.83	3.89	-1.94	-2.92	-7.78	-5.83
92.38	-8.75	-6.80	-1.94	0.97192	-6.80	-18.47	-26.24	-27.21	-24.30	6.80	4.86	15.55	0.97192	0.00000	-4.86	-4.86
92.12	-7.78	-7.78	-4.86	-0.97192	-7.78	-18.47	-28.19	-28.19	-21.38	-0.97192	33.89	34.99	19.44	0.97192	-3.89	-0.97192
91.88	-6.80	-6.80	-3.89	1.94	-10.69	-18.47	-29.16	-31.10	-13.61	2.92	24.30	31.10	30.13	1.94	5.83	2.92
91.62	-4.86	-9.72	-0.97192	2.92	-17.49	-24.30	-30.13	-29.16	-14.58	11.66	37.90	38.88	20.41	7.78	7.78	7.78
91.38	-10.69	-5.83	-3.89	-2.92	-12.63	-24.30	-31.10	-30.13	-13.61	2.92	33.05	36.93	14.58	6.80	14.58	14.58
91.12	-10.69	-15.55	-2.92	-1.94	-14.58	-28.19	-32.07	-21.38	-10.69	9.72	20.41	41.79	38.88	25.27	13.61	15.55
90.88	-13.61	-11.66	-6.80	-9.72	-12.63	-30.13	-34.02	-24.30	-8.75	15.55	24.30	38.88	35.96	22.35	12.63	13.61
90.62	-11.66	-11.66	-9.72	-12.63	-12.63	-26.24	-31.10	-29.16	-22.35	24.30	36.93	38.88	40.82	32.07	22.35	10.69
90.38	-9.72	-9.72	-14.58	-15.55	-23.33	-28.19	-34.99	-29.16	-2.92	51.51	41.79	35.96	41.79	35.96	28.19	16.52
90.12	-10.69	-9.72	-10.69	-18.47	-15.55	-20.41	-33.05	29.16	4.86	41.79	15.40	48.60	40.82	39.85	33.05	13.61
89.88	-8.75	-20.41	-20.41	-25.27	-18.47	-21.38	-30.13	25.27	-8.75	46.65	42.48	46.65	41.79	37.90	29.16	18.47
89.62	-10.69	-13.61	-20.41	-24.30	-24.30	-16.52	-21.38	13.61	-0.97192	60.26	48.32	44.43	43.74	39.85	36.93	22.35
89.38	51.38	19.44	-27.21	-30.13	-24.30	-16.52	-19.44	-8.75	-24.30	17.49	60.26	55.40	41.79	34.02	24.30	20.41
89.12	-14.58	-17.49	-31.10	-29.16	-21.38	-11.66	-13.61	-9.72	1.94	38.88	64.15	53.46	46.65	37.90	32.07	21.38
88.88	-20.41	-16.52	-23.33	-30.13	-19.44	-12.63	-6.80	0.00000	11.66	29.16	63.17	52.20	45.68	34.99	25.27	19.44
88.62	-16.52	-20.41	-36.93	-35.96	-18.47	-7.78	-4.86	4.86	24.30	43.74	63.17	54.43	49.57	34.99	23.33	20.41
88.38	-12.63	-22.35	-31.10	-32.07	-16.52	-6.80	3.89	15.55	33.05	54.43	57.34	54.43	47.62	34.99	23.33	19.44
88.12	-11.66	-32.07	-38.88	-37.90	-21.38	-9.72	0.00000	13.61	25.27	41.79	54.43	54.43	41.71	31.10	27.21	17.49
87.88	-13.61	-26.24	-37.90	-32.07	-25.27	-20.41	-2.92	19.44	25.27	33.05	52.48	53.46	41.79	33.05	24.30	18.47
87.62	-14.58	-29.16	-34.99	-36.93	-22.35	-16.52	-7.78	12.63	21.38	42.76	47.62	46.65	39.85	32.07	21.38	20.41
87.38	-13.61	-28.19	-32.07	-24.30	-10.69	-7.78	0.97192	16.52	26.24	41.79	48.60	46.65	28.19	25.27	23.33	17.49
87.12	-22.35	-28.19	-33.05	-30.13	-9.72	-2.92	8.75	16.52	28.19	48.60	43.74	46.65	35.96	26.24	23.33	20.41
86.88	-25.27	-32.07	-32.07	-32.07	-4.86	-2.92	8.75	18.47	22.35	42.76	44.71	42.76	34.99	26.24	21.38	18.47
86.62	-6.80	-26.24	-32.07	-26.24	-10.69	-6.80	3.89	20.41	26.24	40.82	41.79	40.82	39.85	26.24	22.35	16.52
86.38	-6.80	-24.30	-30.13	-28.19	-13.61	1.94	13.61	16.52	34.99	36.93	38.88	38.88	36.93	29.16	18.47	19.44
86.12	-2.92	-28.19	-29.16	-21.38	-4.86	9.72	25.27	26.24	29.16	35.96	36.93	35.96	35.96	24.30	21.38	18.47
85.88	-9.72	-22.35	-11.66	-22.35	-2.92	6.80	23.33	24.30	31.10	34.02	32.07	36.93	33.05	26.24	19.44	16.52
85.62	-9.72	-14.58	-15.55	-12.63	3.89	12.63	18.47	29.16	24.30	33.05	33.05	34.02	30.13	26.24	23.33	18.47
85.38	-13.61	-2.92	-2.92	-1.94	0.97192	-13.61	-23.33	-33.05	-33.05	-35.40	-30.13	-29.16	-34.02	-25.27	-20.41	-17.49

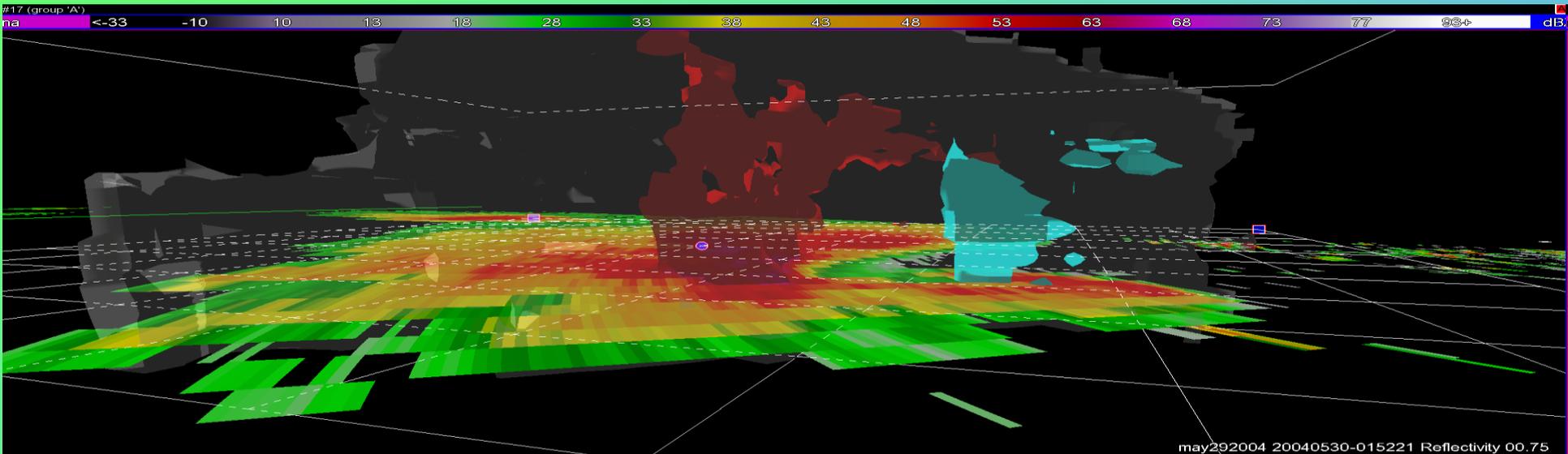
An early example of LLSD for u_s in B-scan coordinates using a 3x3 kernel.

	256.27	256.77	257.26	257.74	258.26	258.76	259.26	259.77	260.25	260.76	261.27	261.76	262.25	262.79	263.26	263.78
94.62	0.00101	0.00040	-0.00121	-0.00172	-0.000910	0.00010	0.00040	-0.00020	-0.010	-0.00151	-0.00172	-0.00162	-0.00131	-0.00121	-0.00121	-0.00121
94.38	0.00152	0.00061	-0.00152	-0.00213	-0.00101	-0.00030	-0.00020	-0.00040	-0.00610	-0.00132	-0.00162	-0.00121	-0.00091	-0.00091	-0.00091	-0.00091
94.12	0.00173	0.00101	-0.00152	-0.00233	-0.00142	-0.00061	-0.00020	-0.00061	-0.00710	-0.00112	-0.00101	-0.00061	-0.00091	-0.00101	-0.00101	-0.00101
93.88	0.00163	0.00122	-0.00142	-0.00254	-0.00183	-0.00081	-0.00020	-0.00071	-0.00710	-0.00031	-0.00020	-0.00041	-0.00112	-0.00092	-0.00092	-0.00092
93.62	0.00092	0.00092	-0.00092	-0.00214	-0.00214	-0.00133	-0.00051	-0.00061	-0.010	0.00061	0.00031	-0.00051	-0.00142	-0.00102	-0.00102	-0.00102
93.38	0.00020	0.00072	-0.00051	-0.00184	-0.00215	-0.00184	-0.00102	-0.00010	0.010	0.00143	0.00041	-0.00082	-0.00153	-0.00092	-0.00092	-0.00092
93.12	-0.000510	0.00041	0.00000	-0.00123	-0.00236	-0.00287	-0.00133	0.00103	0.010	0.00267	0.00021	-0.00154	-0.00164	-0.00113	-0.00113	-0.00113
92.88	-0.000720	0.00062	0.00031	-0.00113	-0.00298	-0.00381	-0.00154	0.00195	0.010	0.00422	0.00021	-0.00195	-0.00206	-0.00134	-0.00134	-0.00134
92.62	-0.001130	0.00093	0.00082	-0.00113	-0.00402	-0.00454	-0.00144	0.00258	0.010	0.00547	0.00010	-0.00165	-0.00206	-0.00186	-0.00186	-0.00186
92.38	-0.001650	0.00134	0.00124	-0.00134	-0.00486	-0.00527	-0.00186	0.00310	0.010	0.00703	0.00227	-0.00041	-0.00383	-0.00321	-0.00321	-0.00321
92.12	-0.002070	0.00145	0.00145	-0.00166	-0.00536	-0.00591	-0.00228	0.00364	0.010	0.00985	0.00518	0.00010	-0.00536	-0.00526	-0.00526	-0.00526
91.88	-0.001870	0.00114	0.00114	-0.00208	-0.00530	-0.00624	-0.00301	0.00457	0.010	0.01289	0.00738	0.00000	-0.00688	-0.00689	-0.00689	-0.00689
91.62	-0.001360	0.00083	0.00083	-0.00261	-0.00584	-0.00584	-0.00186	0.00511	0.010	0.01491	0.00803	-0.00042	-0.00698	-0.00746	-0.00746	-0.00746
91.38	-0.000940	0.00115	0.00073	-0.00282	-0.00617	-0.00533	-0.00052	0.00564	0.010	0.01463	0.00742	0.00010	-0.00698	-0.00721	-0.00721	-0.00721
91.12	-0.001150	0.00115	0.00063	-0.00231	-0.00626	-0.00503	-0.00105	0.00608	0.010	0.01457	0.00713	0.00063	-0.00482	-0.00661	-0.00661	-0.00661
90.88	-0.000840	0.00116	0.00011	-0.00158	-0.00547	-0.00515	0.00095	0.00704	0.010	0.01398	0.00589	0.00063	-0.00263	-0.00596	-0.00596	-0.00596
90.62	-0.000530	0.00042	-0.00053	-0.00116	-0.00443	-0.00495	0.00000	0.00864	0.010	0.01349	0.00358	0.00011	-0.00126	-0.00453	-0.00453	-0.00453
90.38	0.00000	-0.00032	-0.00127	-0.00127	-0.00328	-0.00433	-0.00084	0.01015	0.010	0.01332	0.00159	-0.00085	-0.00127	-0.00370	-0.00370	-0.00370
90.12	-0.00021	-0.00138	-0.00180	-0.00095	-0.00201	-0.00286	-0.00032	0.010	0.02279	0.01420	0.00000	-0.00201	-0.00233	-0.00265	-0.00265	-0.00265
89.88	-0.00149	-0.00223	-0.00202	-0.00053	-0.00032	-0.00085	0.00149	0.008	0.02175	0.01637	0.00021	-0.00319	-0.00372	-0.00276	-0.00276	-0.00276
89.62	-0.00213	-0.00234	-0.00213	-0.00021	0.00117	0.00107	0.00277	0.00629	0.02131	0.01780	0.00011	-0.00373	-0.00486	-0.00320	-0.00320	-0.00320
89.38	-0.00267	-0.00224	-0.00182	0.00021	0.00256	0.00246	0.00321	0.00577	0.01870	0.01774	0.00224	-0.00406	-0.00577	-0.00406	-0.00406	-0.00406
89.12	-0.00193	-0.00214	-0.00193	0.00086	0.00332	0.00322	0.00354	0.00750	0.01661	0.01575	0.00407	-0.00418	-0.00688	-0.00493	-0.00493	-0.00493
88.88	-0.00204	-0.00247	-0.00150	0.00172	0.00430	0.00419	0.00473	0.00903	0.01397	0.01268	0.00473	-0.00376	-0.00763	-0.00623	-0.00623	-0.00623
88.62	-0.00280	-0.00388	-0.00216	0.00302	0.00582	0.00539	0.00604	0.00992	0.01369	0.00970	0.00237	-0.00286	-0.00733	-0.00711	-0.00711	-0.00711
88.38	-0.00411	-0.00530	-0.00249	0.00376	0.00724	0.00681	0.00746	0.00973	0.01275	0.00769	0.00054	-0.00216	-0.00681	-0.00746	-0.00746	-0.00746
88.12	-0.00564	-0.00661	-0.00282	0.00423	0.00791	0.00737	0.00867	0.00932	0.01062	0.00786	0.00130	-0.00217	-0.00681	-0.00674	-0.00674	-0.00674
87.88	-0.00682	-0.00626	-0.00152	0.00348	0.00717	0.00750	0.00924	0.00891	0.00891	0.00783	0.00185	-0.00228	-0.00603	-0.00		

Vertical Cross-Section of u_s



3D Reconstructions



Azimuthal shear (aqua) may be viewed in 3D alongside the high-reflectivity core (red isosurface), 20 dBZ shell (grey isosurface) and 0.5 degree reflectivity scan of a storm. The vertical depth of the storm is about 20 km.

Circulation Center Location

